Smooth Particle Hydrodynamics for Surf Zone Waves

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LONG-TERM GOALS

Breaking waves in both deep and shallow water create turbulent flows, with bubbles and spray. This project is directed towards developing Smoothed Particle Hydrodynamics codes for nearshore wave motions.

OBJECTIVES

The objectives of this project are to improve the SPH model for use in examining the physics of breaking waves, including the description of the wave-induced turbulence and sediment transport within the surf zone. Improvements to SPH have been necessary to improve the ability of the method to treat shallow water flows. To develop a computationally useful model of the full surf zone, which means coupling SPH to a more computationally efficient far-field model.

APPROACH

The approach is based on improving various aspects of the open source SPH code, *SPHysics;* applying the code to more validation tests; and to examine in some detail new aspects of the model by applying it to different situations. A new effort this year has been to begin implementing SPHysics on the GPU for drastic improvements in computational time. A hydrid model, that is, a coupled SPH particle model and conventional finite difference model, the Boussinesq model, FUNWAVE, provides the ability to model large areas.

WORK COMPLETED

FYO8

- Our SPH code, SPHysics, is open source and available on the web:
  http://wiki.manchester.ac.uk/sphysics
  Version 1.0 was released August 1, 2007. Version 1.2, with faster link lists, moving least squares, and new options was released on April 22, 2008.

- Validation of the SPH hydrodynamics calculation is being carried out through comparisons to laboratory experiments.

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- Stability of SPH has been improved by the implementation of kernel correction (Chen *et al.*,1999)
- Coupling of SPH with a Boussinesq model has been implemented and is in testing.
- Early results have been obtained for running SPHysics test case 1 on a GPU card, with impressive code speed-ups.

RESULTS

SPH Code Improvements: A major effort was taken to improve the stability of SPH. The SPH particles, which represented both fluid parcels and moving irregularly spaced nodal points of a numerical model, traditionally move chaotically, partially due to acoustic noise in the model solutions, but more due to slight mis-matches in the model calculations. We have long used a normalized kernel for our integral interpolant and periodic Shepard filtering (a renormalization of the density), which improves the behavior of the model near the free surface and boundaries, but the vibrations of the particles persisted. One of the strengths of SPH is that the derivatives of such quantities as pressure are determined analytically, but Bonet and Lok (1999) and Chen *et al*. (1999) have pointed out the necessity of correcting these calculations for derivatives. We have implemented Chen *et al*'s methodology and a much smoother model result occurs, both for fluid motions but also the free surface smoothness and the pressure, which is denoted in Figure 1 by colors. Figure 1 shows a two dimensional result of a dam break wave hitting a wall. The upper panel shows the corrected derivatives method, while the lower panel shows the original SPHysics results.

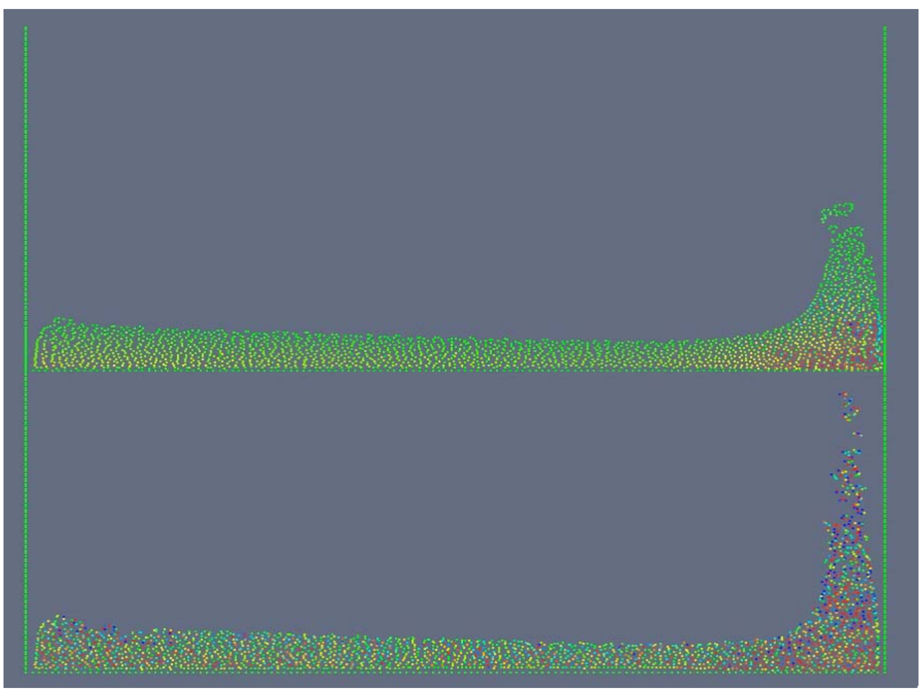

Figure 1 Results for two-dimensional dam break wave impinging on a wall (at the right). The upper panel includes kernel correction for derivatives, while the lower panel is the original SPHysics result. The improvements in the upper panel include a smoother pressure distribution in the water (denoted by colors), and a smoother free surface.

Hydrodynamics Validation: Duncan's fluid mechanics group at the University of Maryland has carried out a series of experiments on ship bow wave generation, Shakeri *et al.* (2008). The

experiment proceeds by moving a wave paddle in a wave tank in a way that represents a ship steaming perpendicular to the tank. The ship draft is one half the depth of the wave tank. The wavemaker motion can be envisioned as following a sequence of ship cross-sections starting at the bow (except only the right half of the crossection is used, since waves are only generated for one side of the ship). We have programmed the wavemaker motion into the SPHysics model and carried out a variety of runs to improve the accuracy of our SPHysics code. A difficulty associated with the modeling is that the resolution of the numerical modeling has to be very high to capture the bow wave that occurs over a very small portion of the physical tank.

Incompressible SPH: A working version of an incompressible SPH code has been developed. While this is not news on the research front, the model will be put into the SPHysics framework, such that we have both an incompressible and compressible version of the model. The advantage of an incompressible model is larger time steps, the disadvantage is that more computations are needed to compute the pressure.

Coupling: We have nearly completed a coupling of the SPH model (for the nearshore, where wave breaking occurs) and the far field, which is modeled with the Boussinesq model FUNWAVE. The modeling involves an overlap region, where both models coexist and provide feedback to one another. This is a vast improvement over our one-way coupling model (FUNWAVE-→ SPH only, Narayanswamy and Dalrymple, 2005).

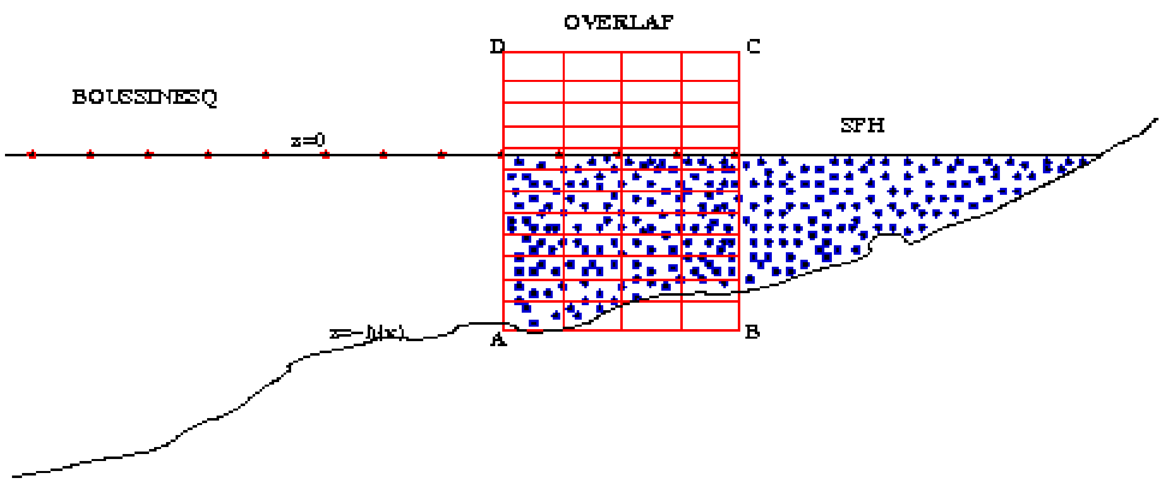

Figure 2 Sketch of coupling problem, with the Boussinesq model FUNWAVE to the left, an overlap region denoted with the red lines, and then the SPH region at the shoreline.

GPU Modeling: One of the most remarkable technological revolutions underway today is the use of a computer's Graphical Processing Unit (GPU) for scientific computation. Using the extraordinary power of the modern graphics card for numerical computations allows everyone to have supercomputing capabilities at small cost. We have purchased an Nvidia GeForce 8800 GT card with 112 streaming processes for use in GPU programming of SPHysics and are anxiously awaiting the appearance of the NVIDIA Tesla card on the market (late October, 2008). This graphics card (already available in a gaming version) will permit terraflop computing for several thousand dollars. It will have 240 streaming processors, 4 Gb on-board memory, and the ability to do double precision

arithmetic. In addition we have a MacBook Pro laptop with a Nvidia GeForce 8600 M GT GPU, with 32 streaming processors.

We have a working relationship with Dr. Alexis Herault, University of Catania, Italy, who has developed working GPU code to model dam break problems using the SPHysics equations. At the present time, we have been benchmarking his code for different size machines to examine speed ups that are available. For example, we know that GPU accelerated code running on an NVIDIA GTX 280 speeds up the computation of interactions between particles by over 150 times that for a single processor and we find an over 80 times speed-up for our 8800 card.

The result of this collaboration is that we can now easily run nearly 700,000 particles in our SPH simulations—even on a laptop! At present we can not do more, as both of our graphics cards are limited to 512 Mb of memory. As an example, Gómez-Gesteira and Dalrymple (2004) examined the impact of a dam break against a rectangular structure in 3-D application of SPH code. They used 34,000 particles to model the problem (of which only 15,000 were fluid particles, the rest were used to model the solid boundaries of the structure and the bounding box). In Figure 1, the exact same problem is shown with 677,360 particles with 592,020 fluid particles. The elapsed clock time on a Macbook Pro laptop (with 32 streaming processors—Nvidia 8600 GT card) was 43 minutes (corresponding to 0.493 seconds post dam break, or about 0.011 s simulation time per one minute wall time) versus a whole day if using a single processor.

Active programming is underway to introduce a wavemaker and a sloping beach so that surf zone waves can be readily modeled. The Tesla card will permit over 3 million particles to be used in the simulations. SPH is ideally suited for GPU programming as it tends to be computational intensive, but data sparse (important as the on-board memory per processor for a GPU is much lower than for CPUs).

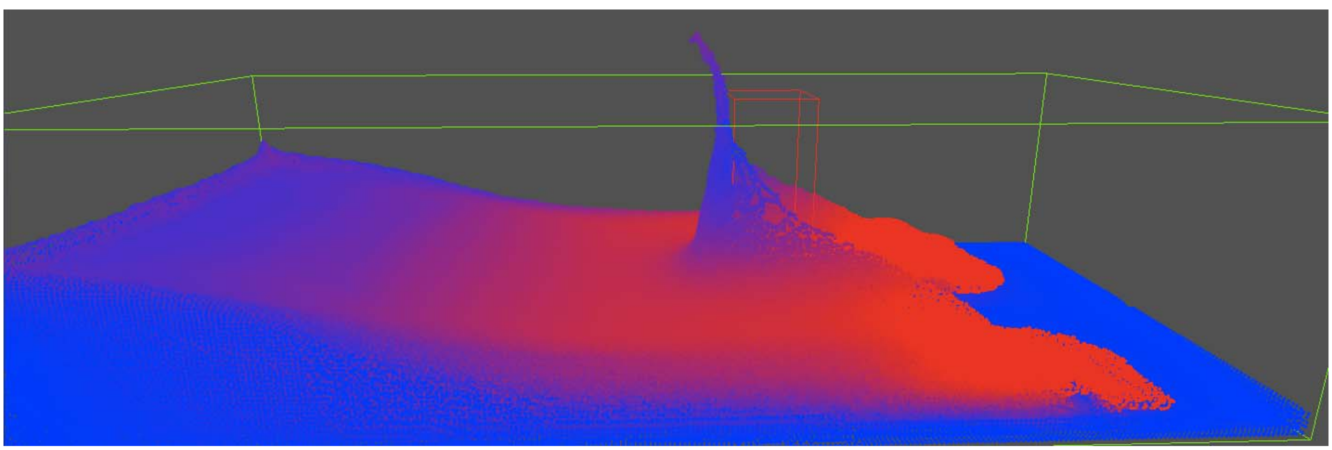

Figure 3 GPU-SPH of dam break impacting a rectangular structure using 677,360 particles. Run-up jet on the front face of the structure was not observed in the much lower resolution results of Gómez-Gesteira and Dalrymple (2004). Colors represent velocity with bright red being the fastest velocity.

International Collaborations

The SPH project at Johns Hopkins University, which we consider as a major part of an open source effort, SPHysics, has benefitted from collaborations with individuals from a number of European universities. Collaboration with Dr. Moncho Gomez-Gesteira (University of Vigo) and Dr. Benedict Rogers (University of Manchester) continues. A meeting was held in Vigo, Spain this year for four days, where the three of us worked on improvements to the SPHysics model. In addition, the meeting coincided with the dissertation defense of Dr. Alejandro Crespo, who has been active in SPHysics development. In addition, all four of us presented a half-day shortcourse on SPHysics at the SPHERIC (ERFCOTAC) meeting in Lausanne, Switzerland, June 3, 2008.

A new collaboration is the GPU work with Dr. Alexis Herault, University of Catania. Dr. Herault will visit Johns Hopkins University in January, 2009 to further our collaboration on GPU programming.

IMPACT/APPLICATIONS

Smoothed Particle Hydrodynamics is proving to be a competent modeling scheme for free surface flows in two and three dimensions. Coupled with another wider-area wave model, such as Boussinesq, a hybrid SPH model would provide a large, highly resolved, look at an entire surf zone.

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